Computational Insights into Population Biology

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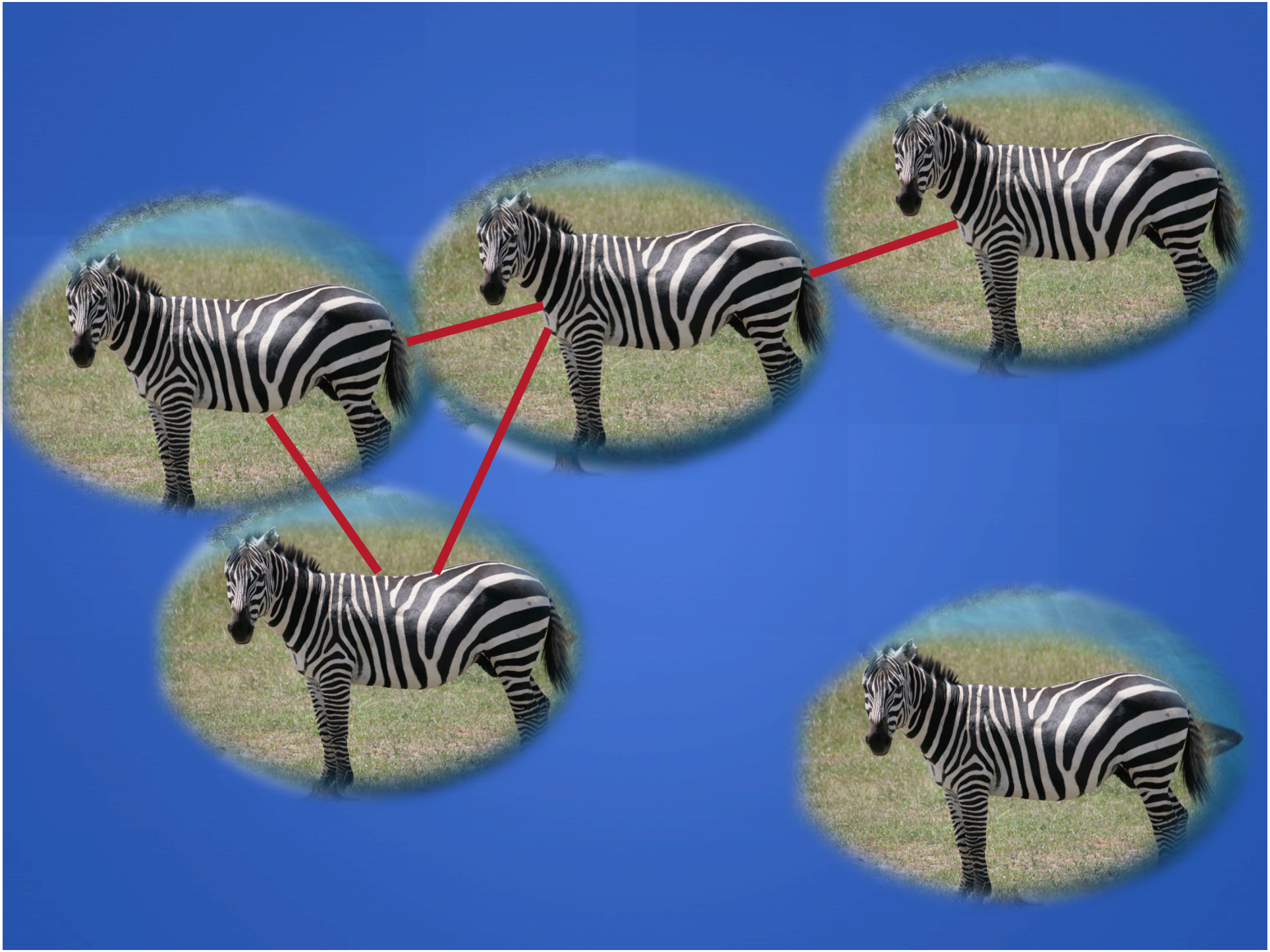
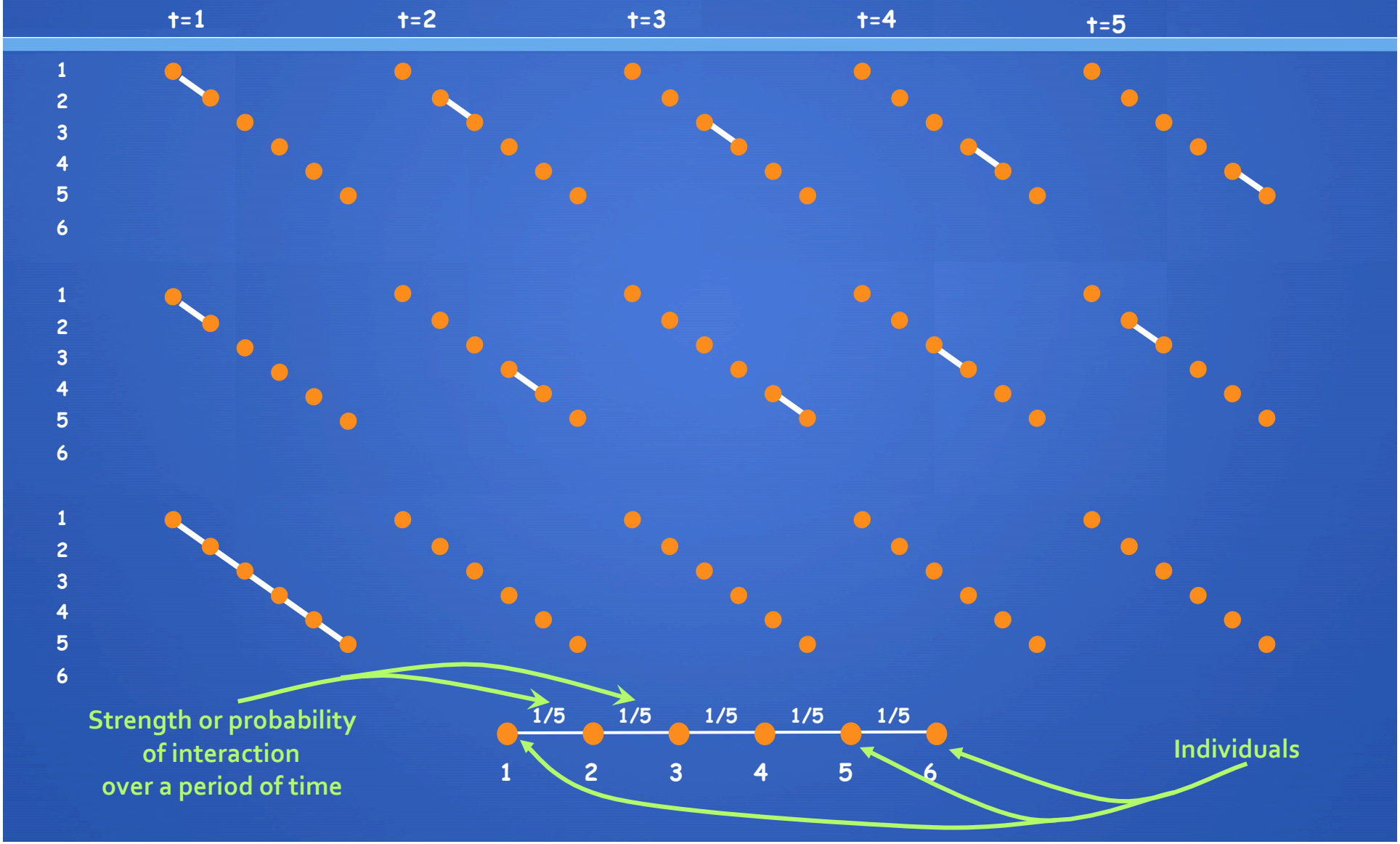


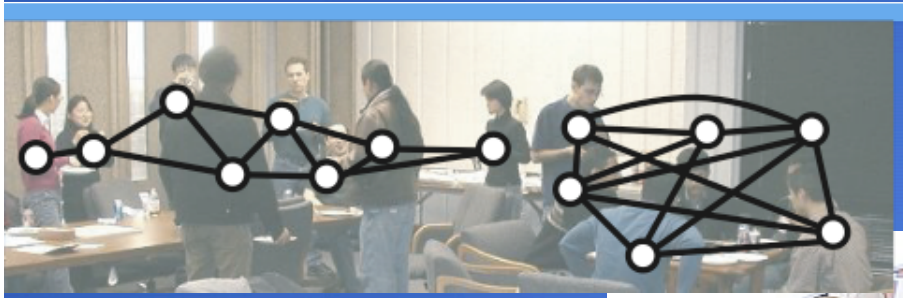
Social Networks: Static vs Dynamic

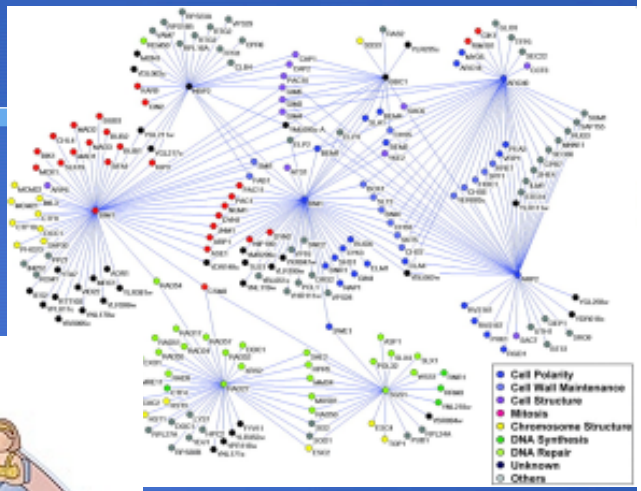


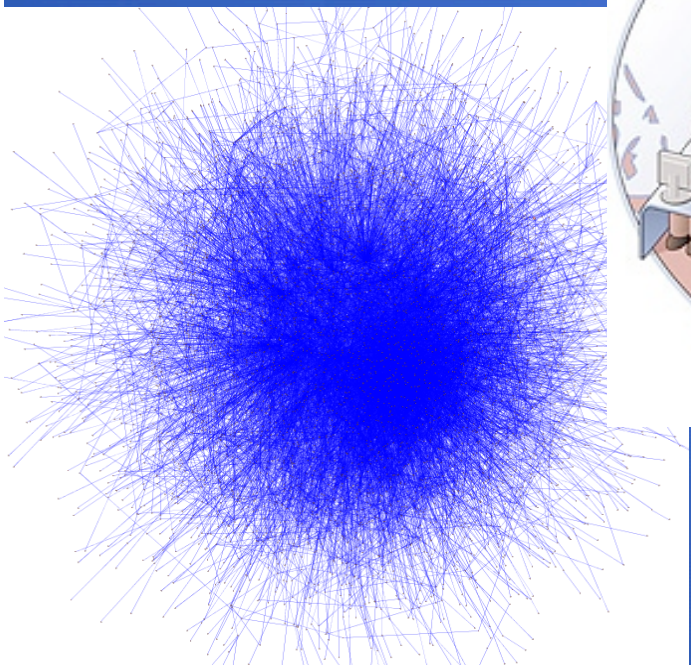
Advantage of Dynamic Networks:

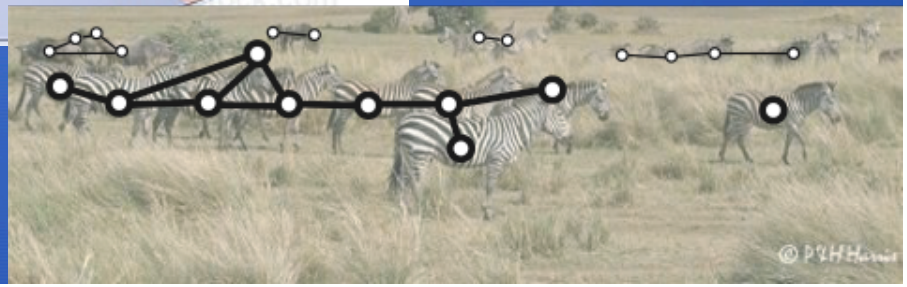
- More accurate information
- Time related questions:
  - How do diseases/information spread through population?
  - Who are the individuals that change the dynamics of interaction (leaders, interaction facilitators, etc.)? How do they emerge?
  - How do social structures (communities) change with outside circumstances ?
  - What is the average lifespan of a social structure and are there recurring structures?

Dynamics Networks

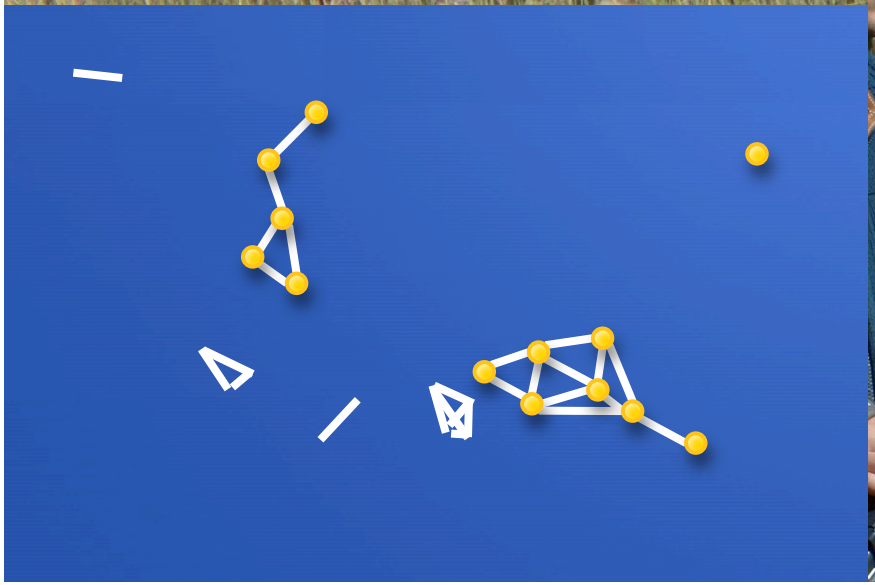


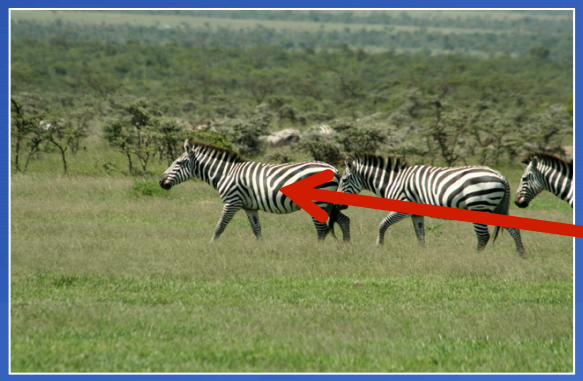




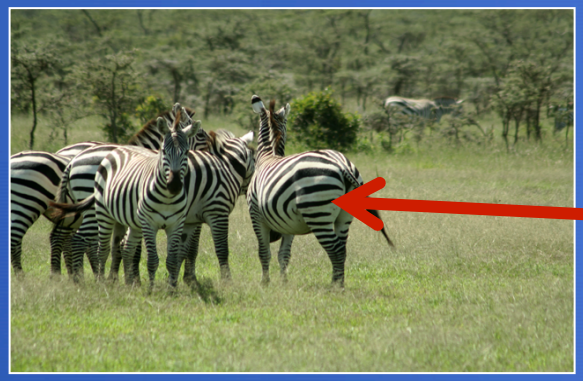


How do we get individual information?





"Moe"
April 23



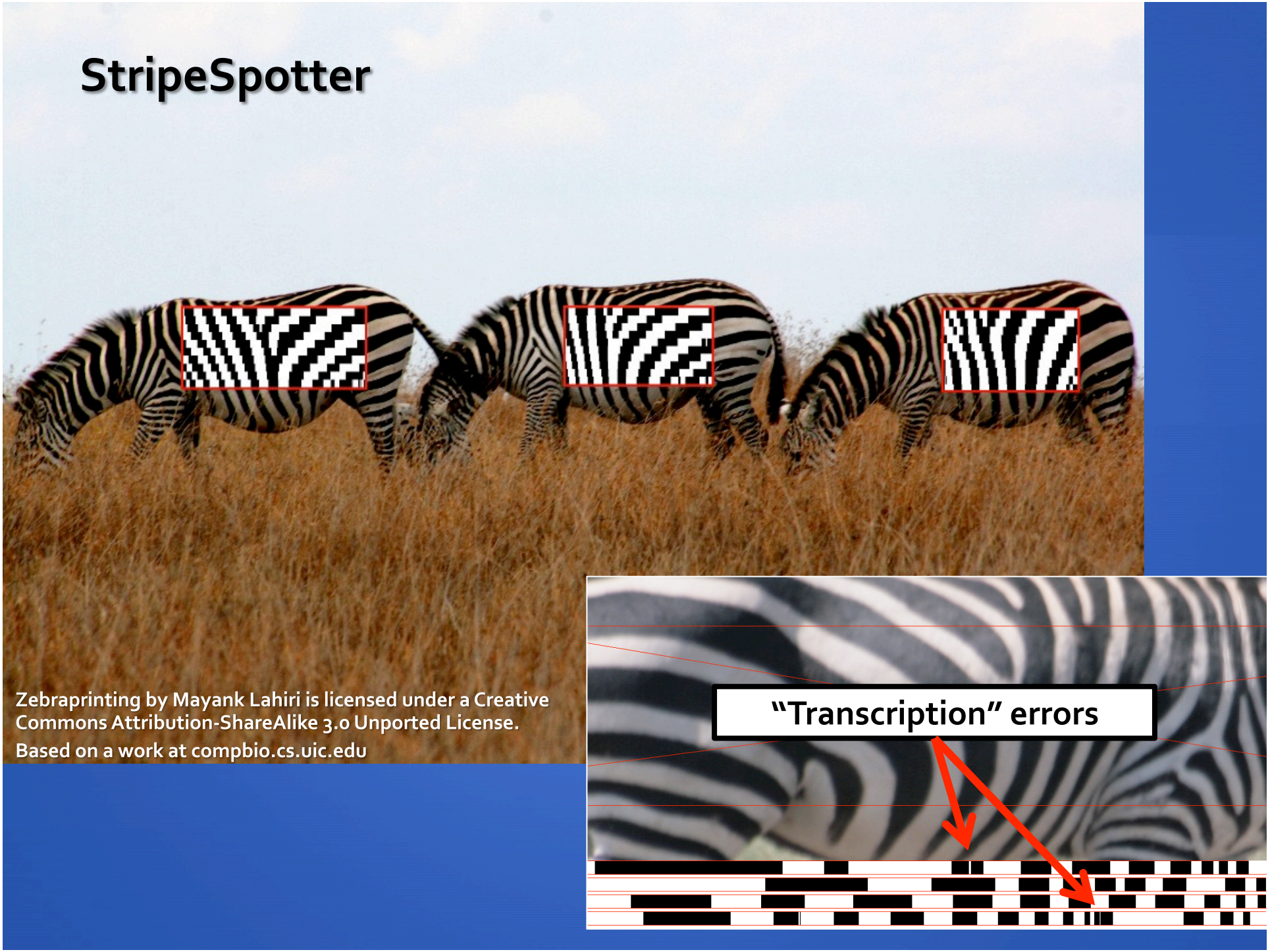
"Moe"
June 6

Telling zebras apart is a hard road
and I'm making mistakes by the car load.
So I got this device that keeps track of their stripes
and just scans them like they are a … BARCODE!

NPR, Wait Wait Don't Tell Me, April 16, 2011

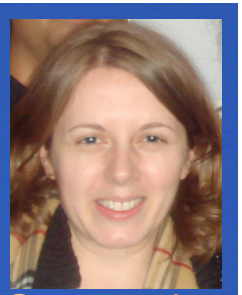
Image: Tim Flach/Getty

StripeSpotter

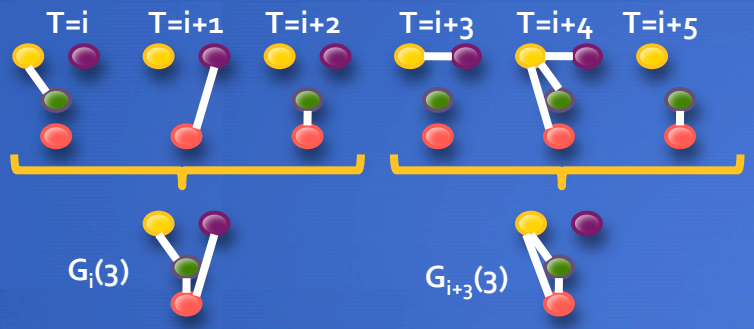



16
15
15

What is a time step?



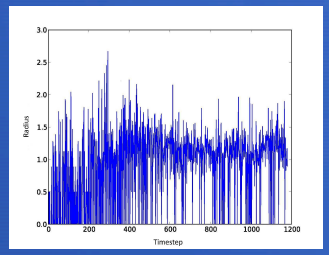
Sulo Caceres, B-W , Grossman '10

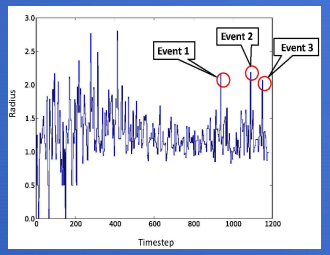


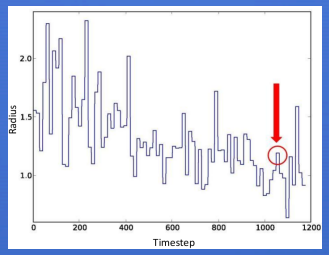
Temporal **W**indow **I**n **N**etworks Algorithm:

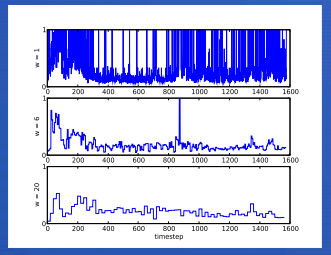
1. Given a graph sequence, compute the time series of the measure defined over a dynamic network with fixed resolution w.
2. Let **Variance** of the time series to represent noise. Let **Compression ratio** of the time series represent information.
3. Pick the window values for which Variance is low and compression ratio is high.

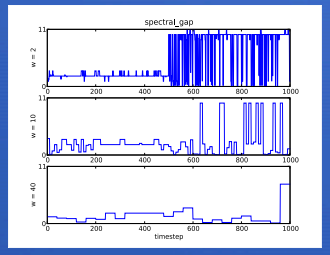
Any noisy stationary probabilistic process that generates the edge stream, which is oversampled at factor *w* will be stationary at aggregation window *w* and not less.

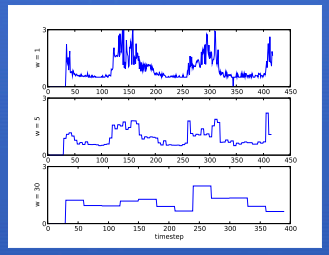


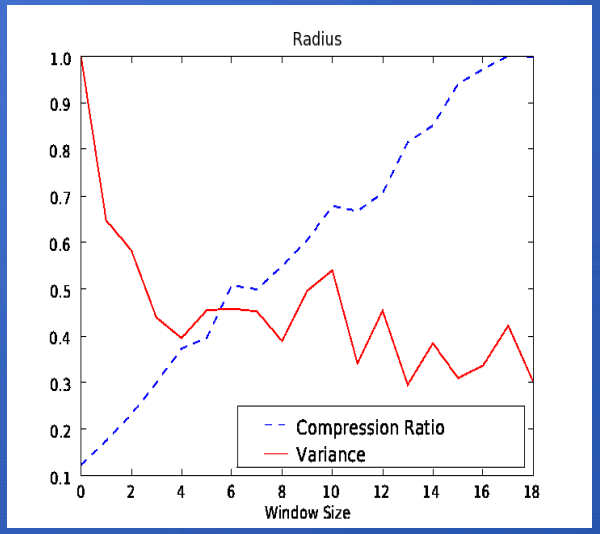






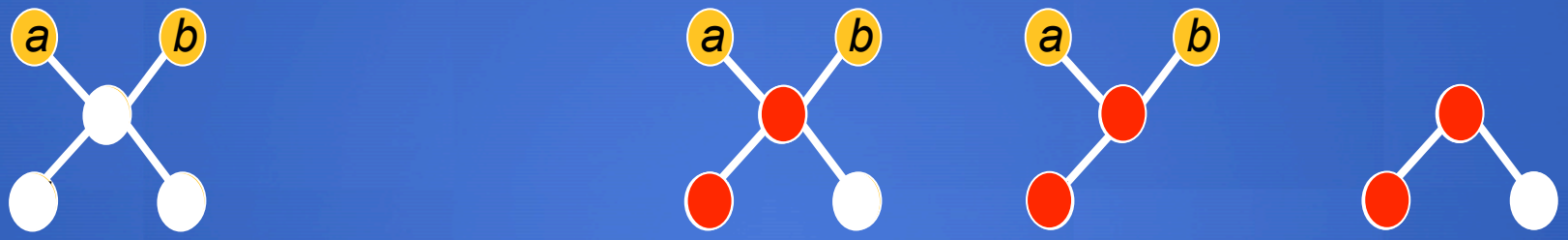






Periodic Pattern Discovery

Lahiri & B-W '08 + '10



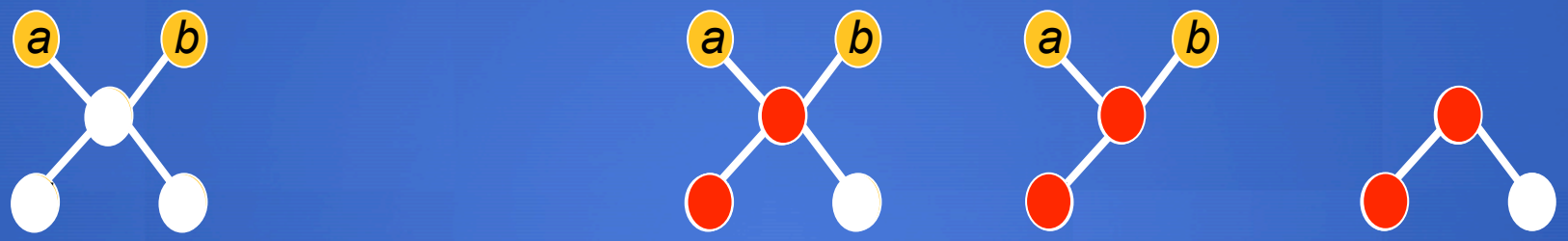
t = 1 *t = 2* *t = 3* *t = 4* *t = 5*

Given a dynamic network, find all subgraphs that occur periodically more than σ times.

Downward closure: Any subgraph of a periodic subgraph is also periodic.

Periodic Pattern Discovery

Lahiri & B-W '08 + '10



Given a dynamic network, find all subgraphs that occur periodically more than σ times.

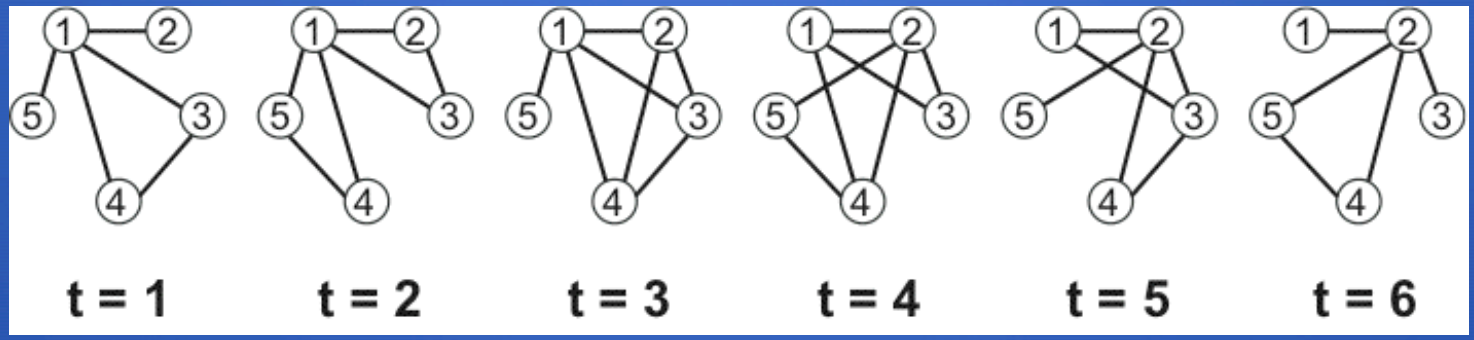
1. Occurs more than σ times
2. Cannot be extended structurally
3. Cannot be extended in time

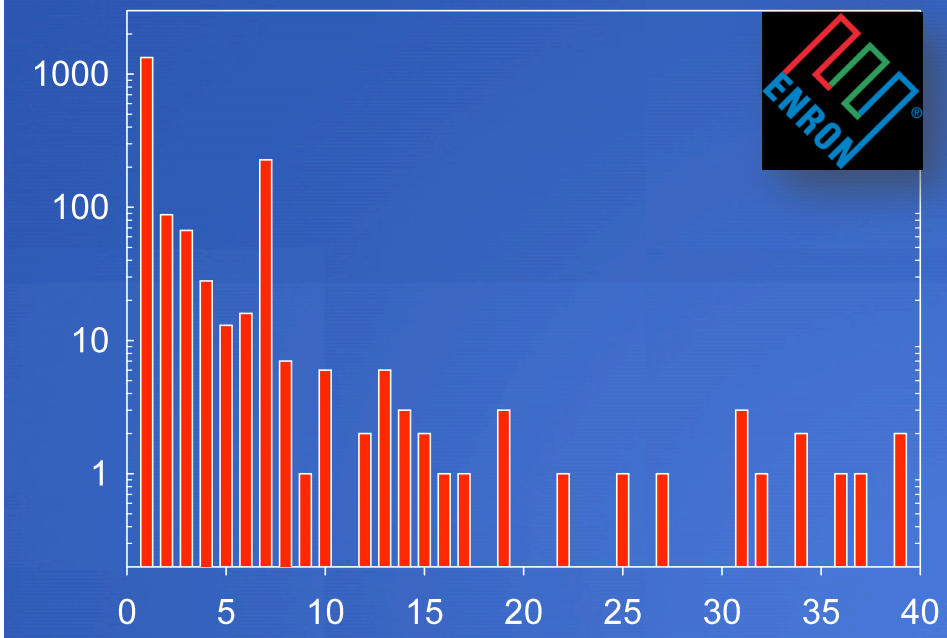
} Closed periodic subgraphs

Periodic Pattern Discovery

- In a finite amount of data:
  - Maximum period has a natural upper bound
- Construct worst-case example from a mining point of view
  - Each possible periodic subgraph is present
  - Iterate over all possible periodic positions, "creating" a new subgraph
  - Polynomial number of closed periodic subgraphs.
- Algorithm to enumerate this is $O(T^2 \ln(T/\sigma) (V+E))$*

  * When each graph has unique node labels

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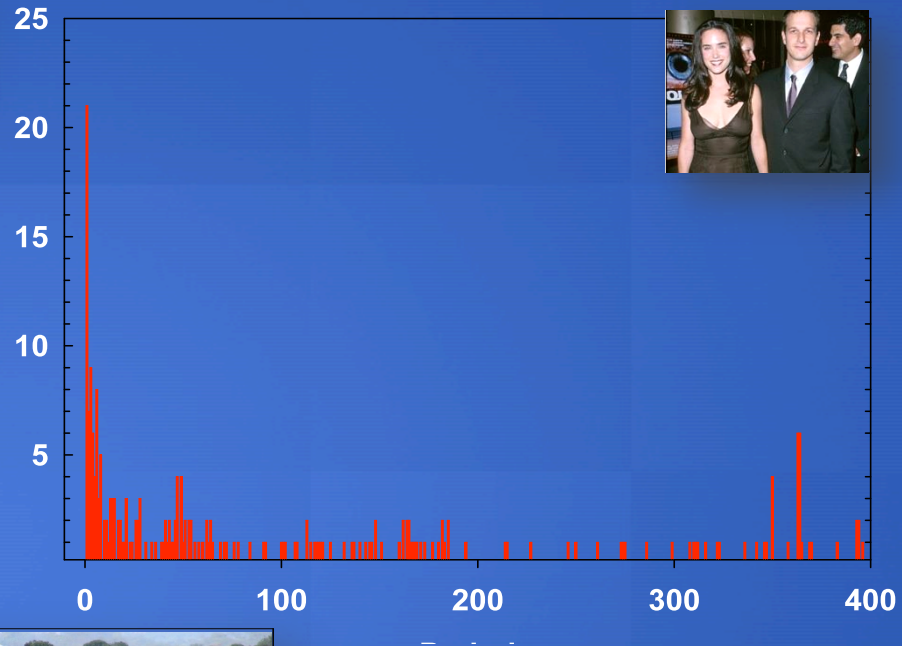
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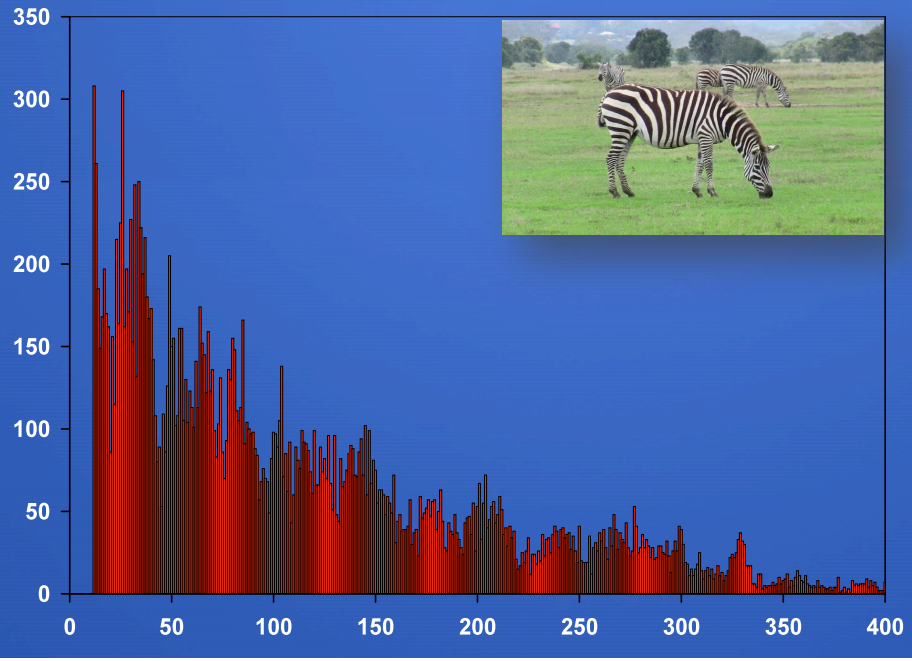
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IMDB.com

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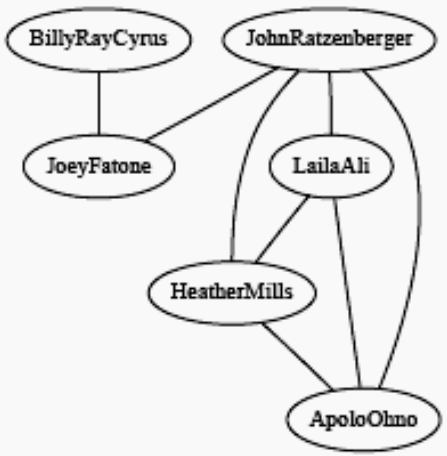
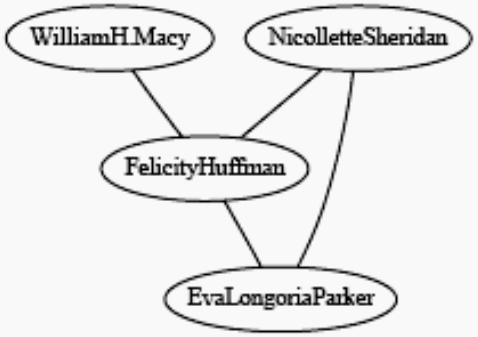
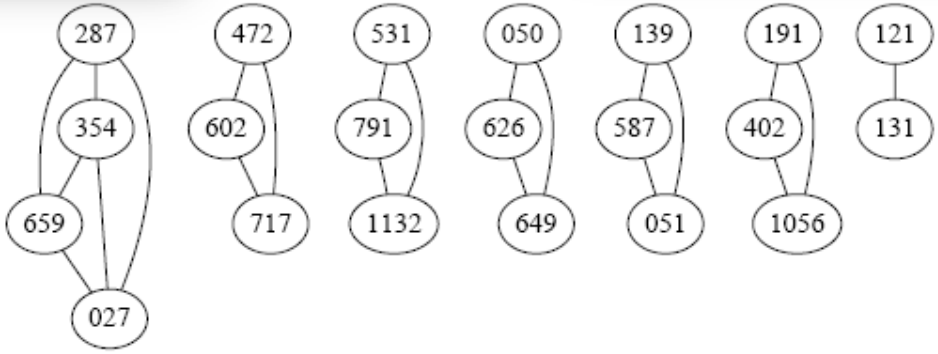


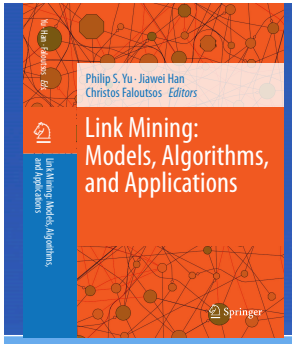
(a) IMDB: period 7 ± 2, support 3, avg. purity 1



(b) IMDB: period 364, support 3, avg. purity 0.4

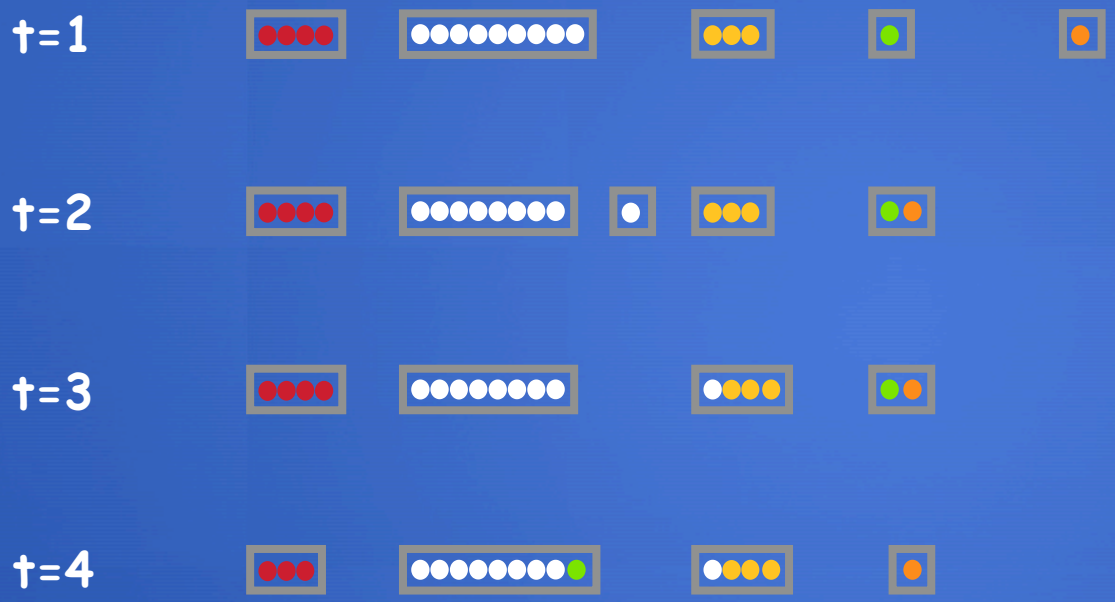


(d) Plains: period 7, support 4, avg. purity 0.94.



Dynamic Communities

Tantipathananandh, TB-W & Kempe '07
Tantipathananandh, TB-W '09



Individuals change affiliations, group split and merge

Are there cohesive groups?

How does community structure arise from interactions and how are the interactions affected by the latent community structure?

Want to allow fluid community structure

Dynamic Communities

What is a community?

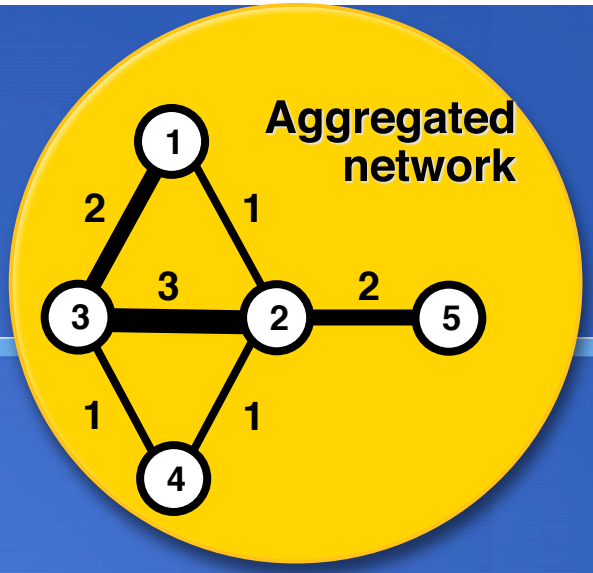
"Cohesive subgroups are subsets of actors among whom there are relatively strong, direct, intense, frequent, or positive ties." [Wasserman & Faust '97]

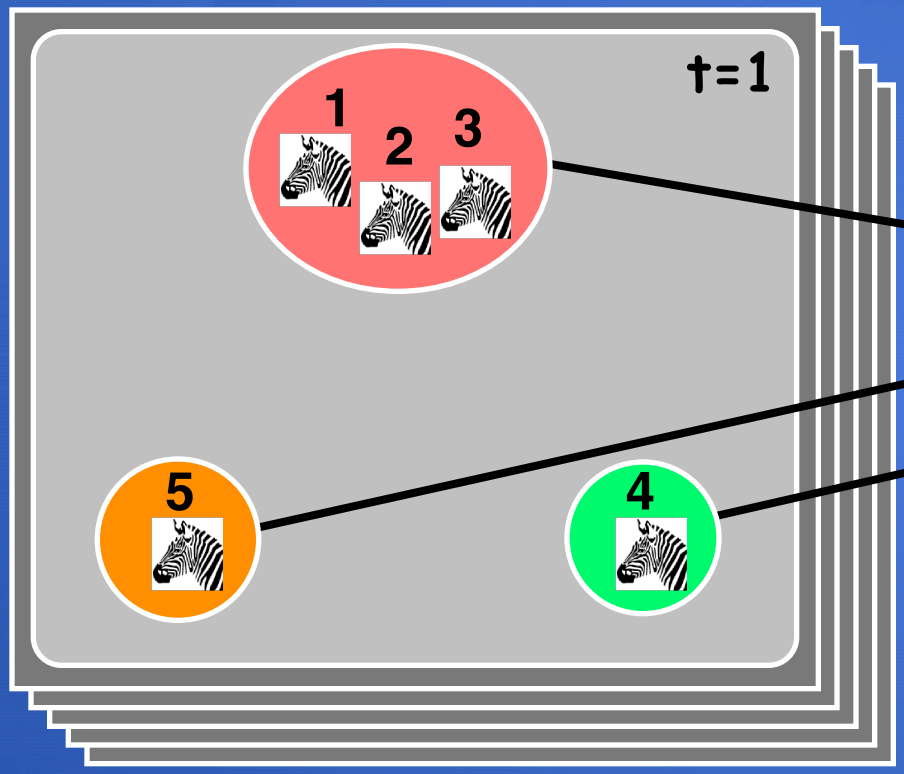
Community = cluster
Dynamic community = dynamic cluster: members of community interact more frequently (consecutively) among them than with individuals outside the community.
Dynamic community = identity.

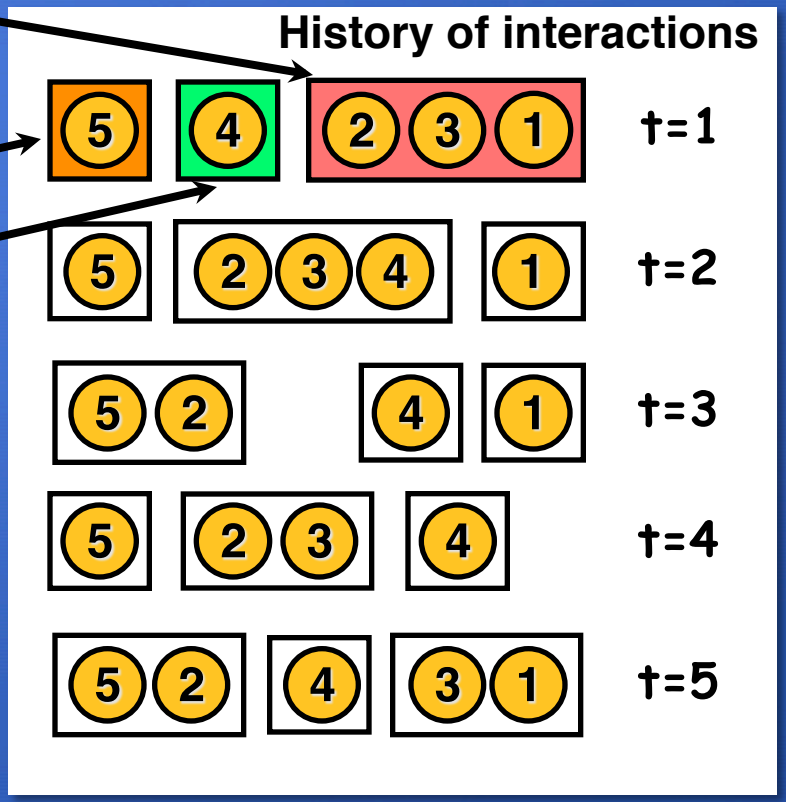
Computational Approaches

- Aggarwal and Yu '05
- Metagroups [Berger-Wolf & Saia '06]
- MONIC [Spiliopoulou et al '06]
- Palla et al '07
- Falkowski et al '06
- GraphScope [Sun et al '07]
- FacetNet [Lin et al '08], Yang et al '09, Colibri [Tong et al '08], Sarkar and Moore '05, Fu et al '09

Formal Representation

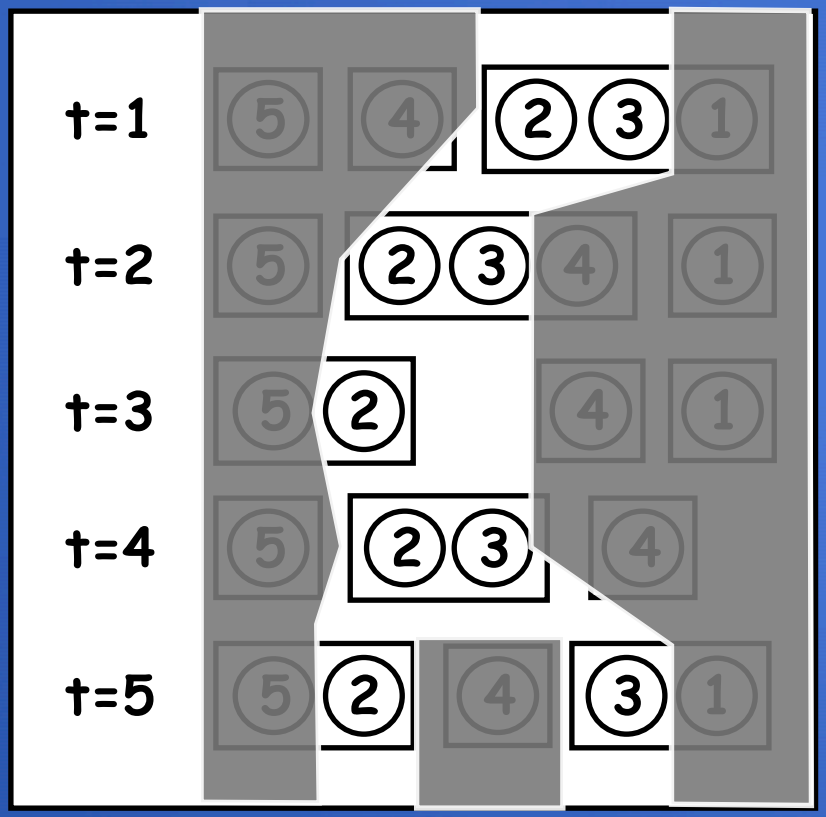






Assume discrete time and interactions in form of complete subgraphs.

The Question: What is dynamic community?



- A dynamic community is a subset of individuals that stick together over time.
- Community is a latent object
- Community = object's identity
- NOTE: Communities ≠ Groups

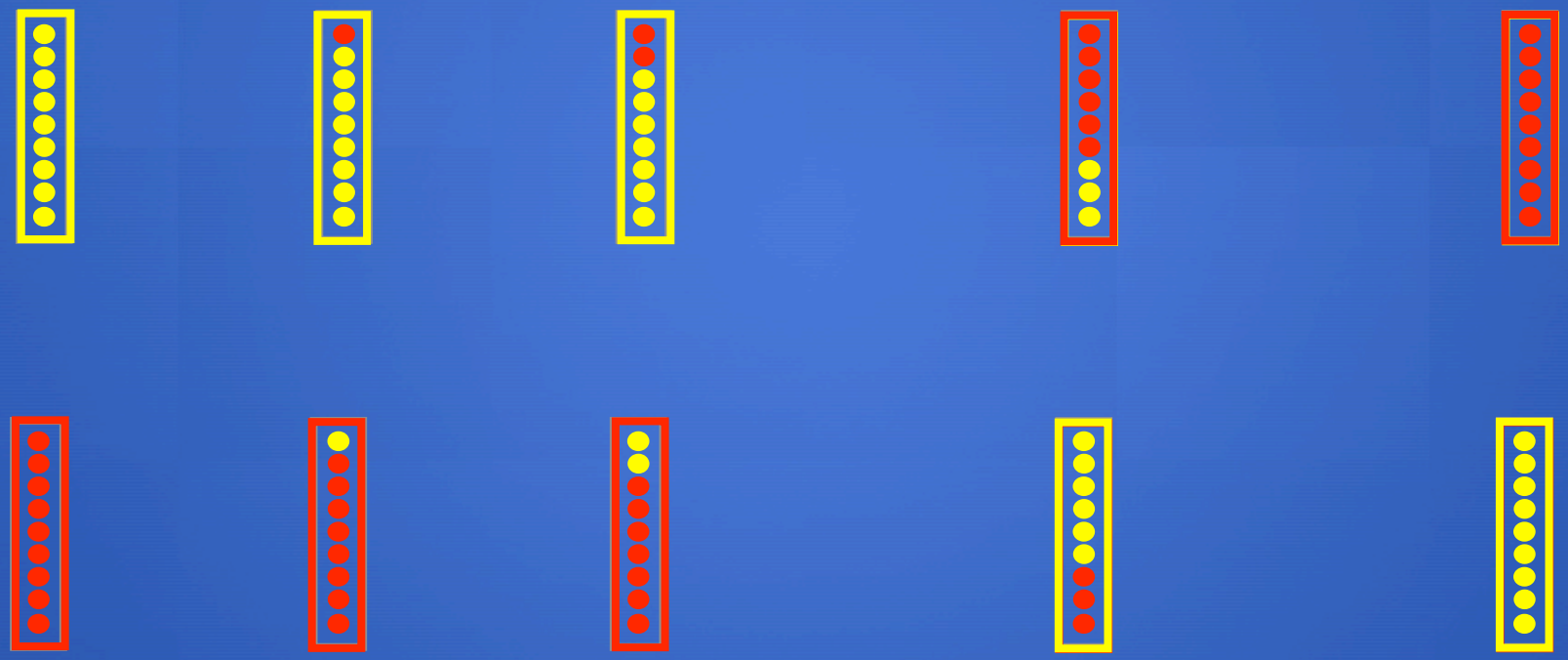
Theseus's Paradox

- During a twelve month period 95% of all the atoms that make up your 50 trillion cells are replaced
- FAA regulations: airplane = left rudder number
- **Ship of Theseus**

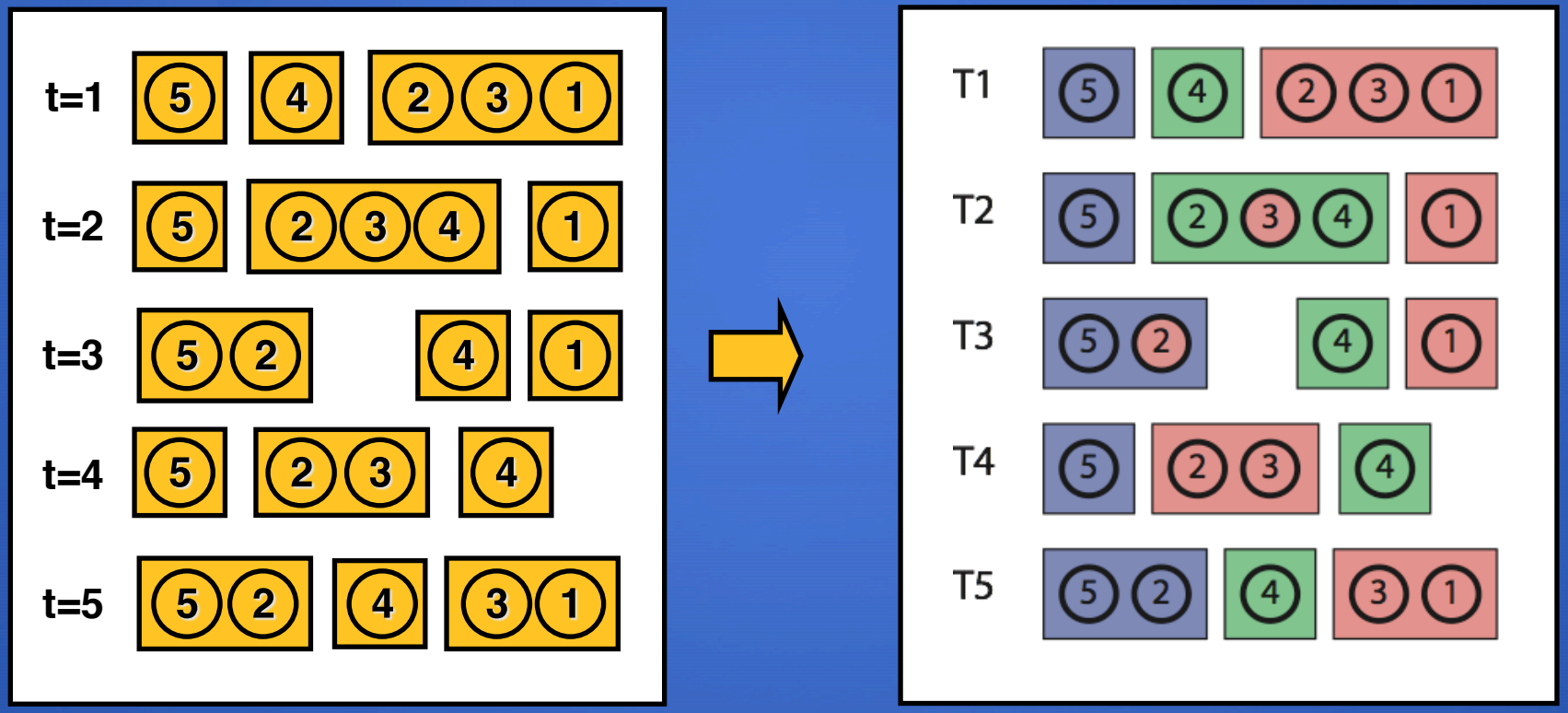
  "The ship wherein Theseus and the youth of Athens returned [from Crete] had thirty oars, and was preserved by the Athenians down even to the time of Demetrius Phalereus, for they took away the old planks as they decayed, putting in new and stronger timber in their place, insomuch that this ship became a standing example among the philosophers, for the logical question of things that grow; one side holding that the ship remained the same, and the other contending that it was not the same."

Theseus' Ship as Dynamic Community

t=1 t=2 t=3 … t=7 … t=10



Community = Color



Assumptions

- Individuals are reluctant to switch community affiliations
  cost of switching
- Individuals mostly are seen with their own community
  cost of visit
- Individuals a rarely absent from their own community
  cost of absence

Parsimony = minimize the total cost across all individuals

Community as a Coloring

Minimum Community Interpretation:

For a given cost setting, $(\alpha, \beta_1, \beta_2)$, find vertex coloring that minimizes total cost.

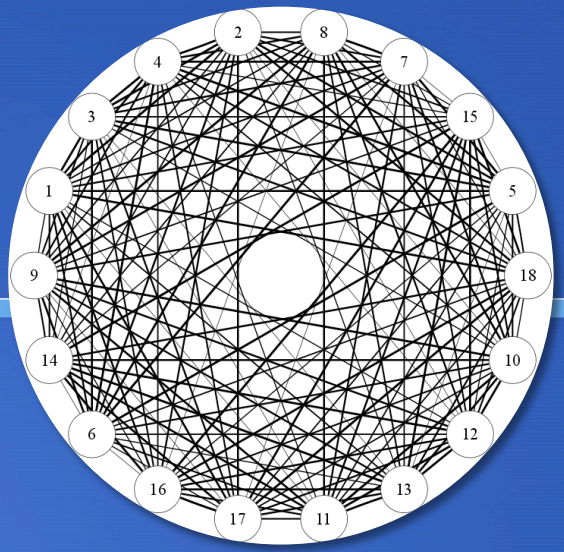
Color of group vertices = Community structure

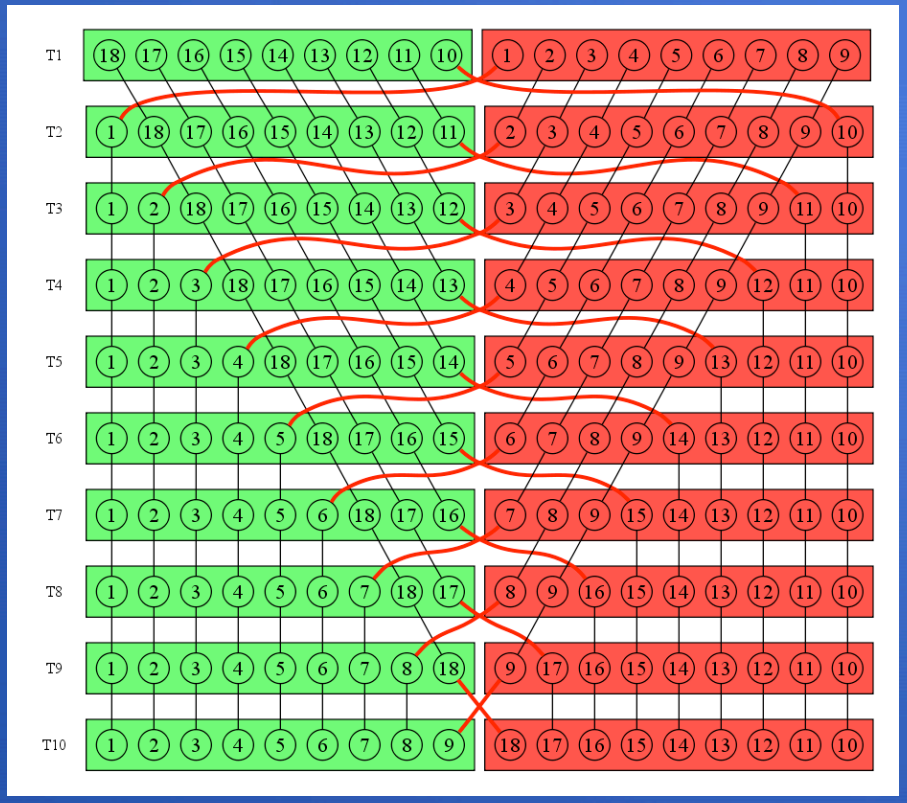
Color of individual vertices = Affiliation sequences

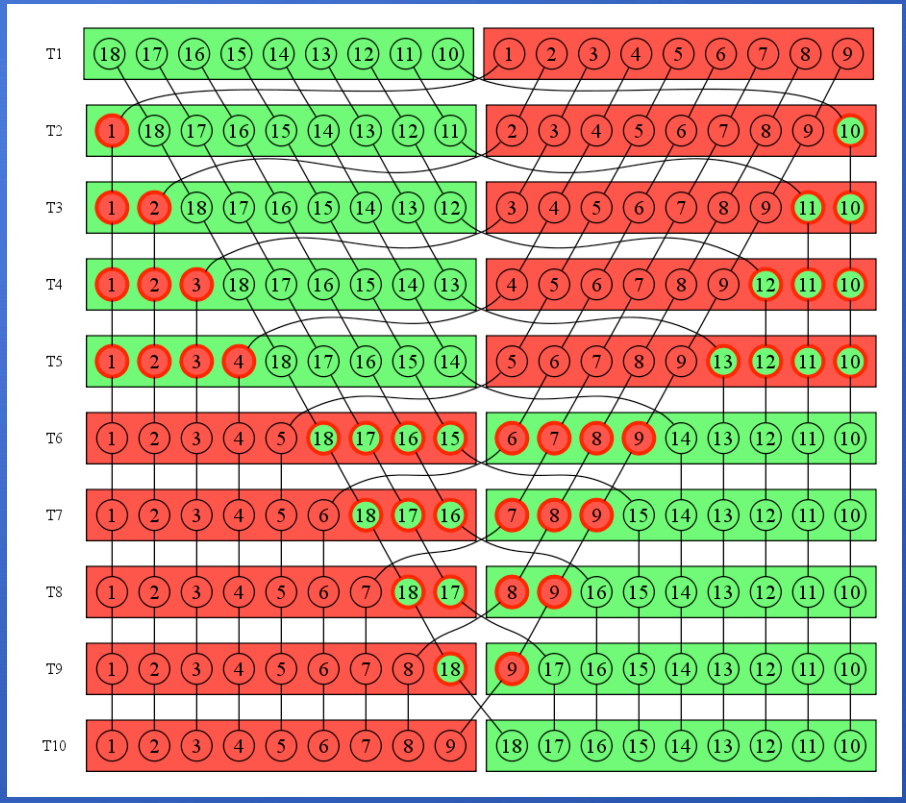
Problem is NP-Complete and APX-Hard

But fast flow-based constant factor approximations

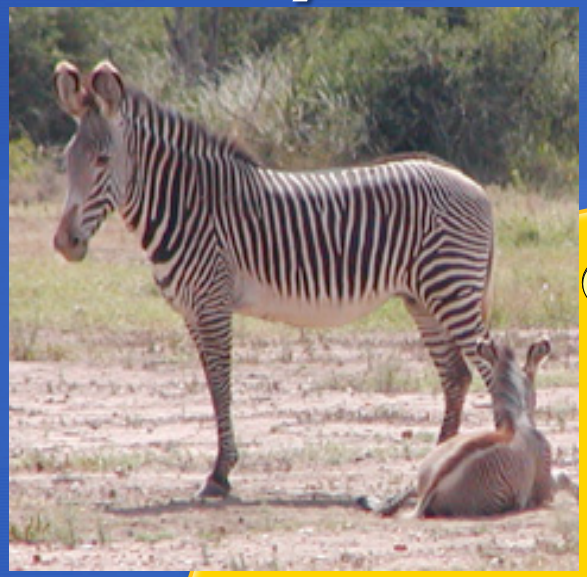
Theseus' Ship

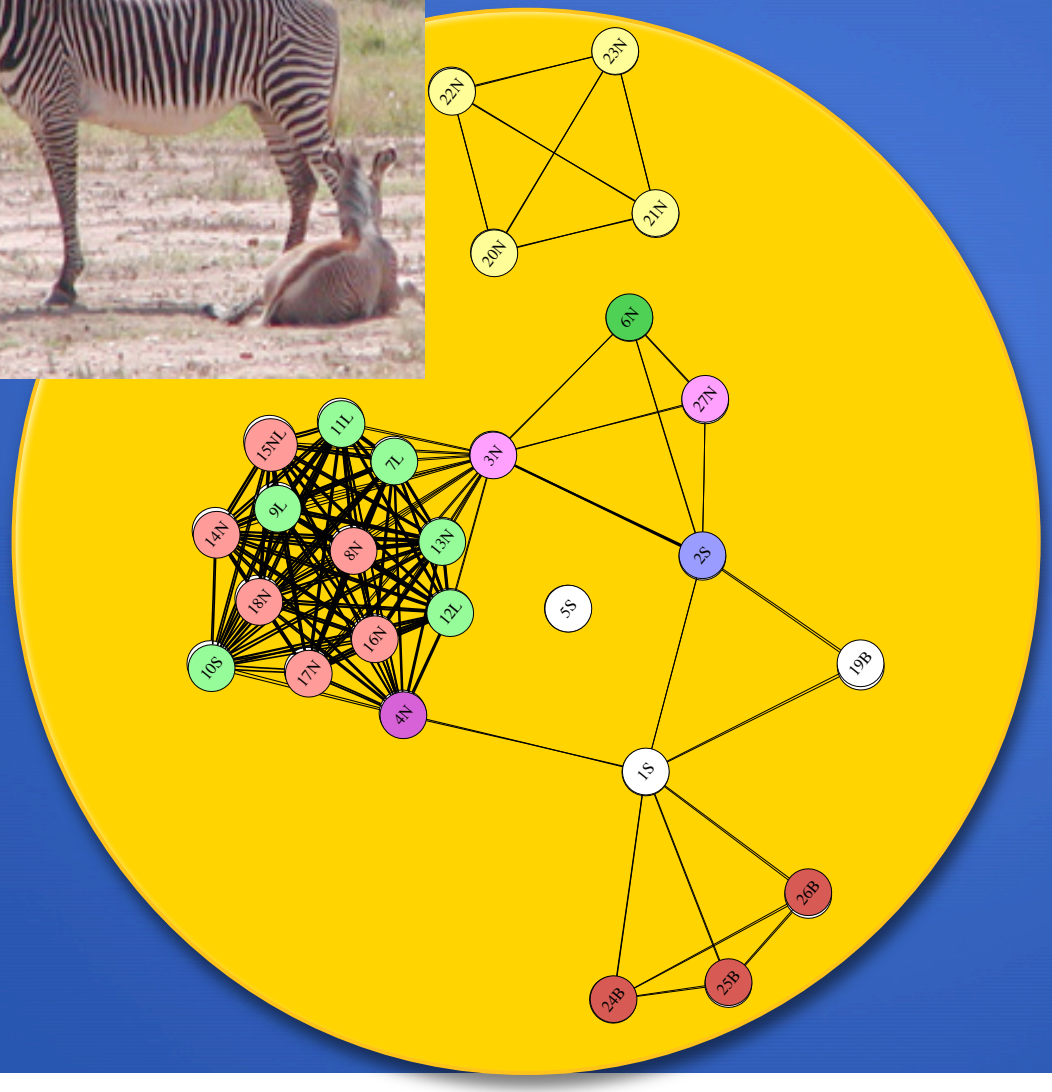


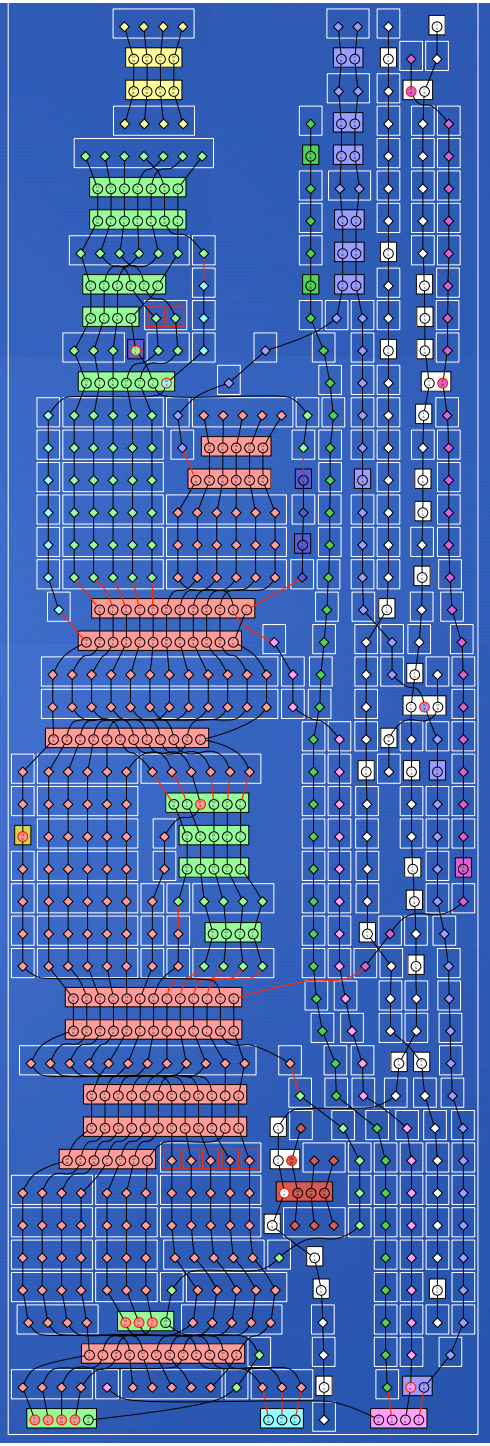


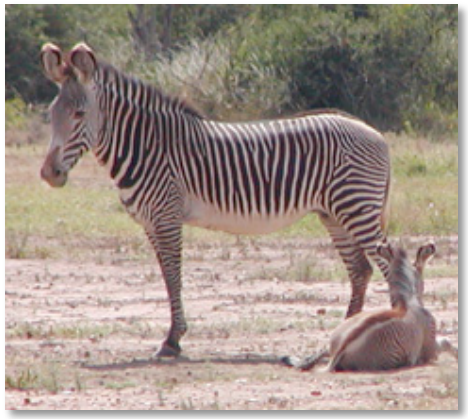


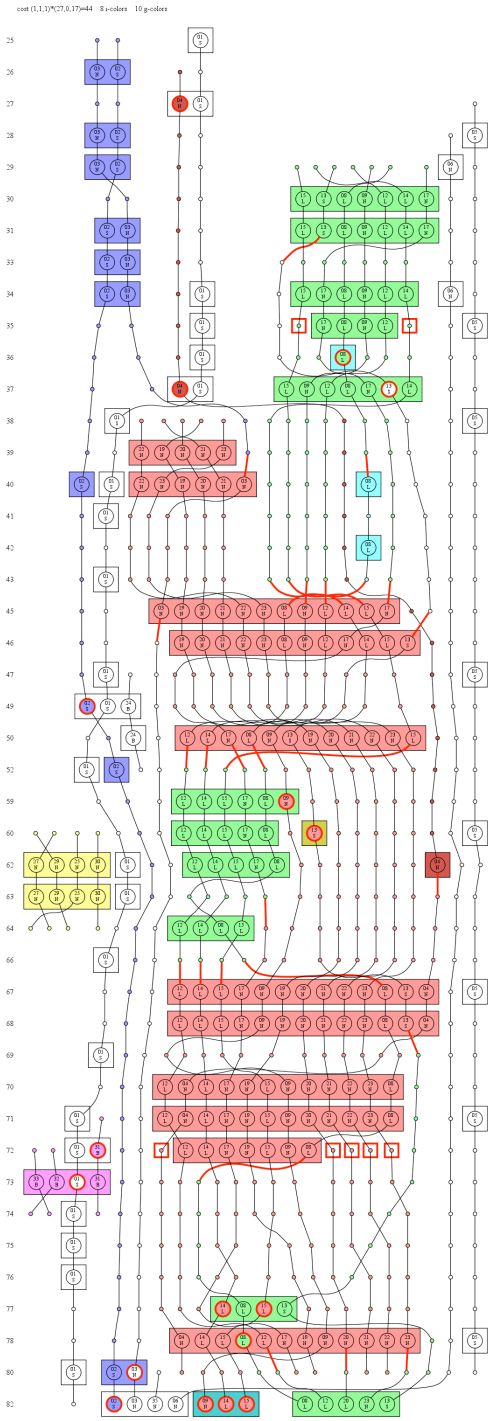
Grevy's Zebra

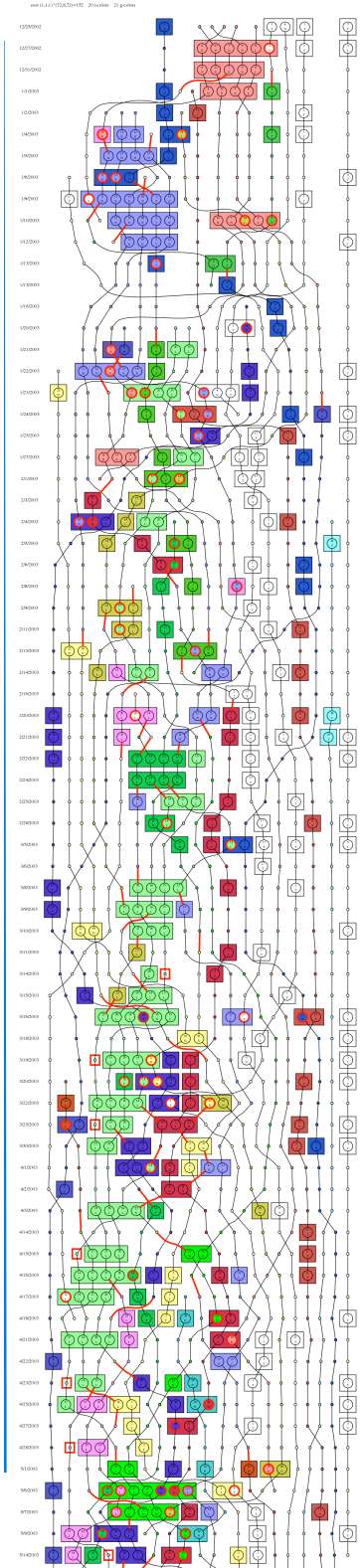


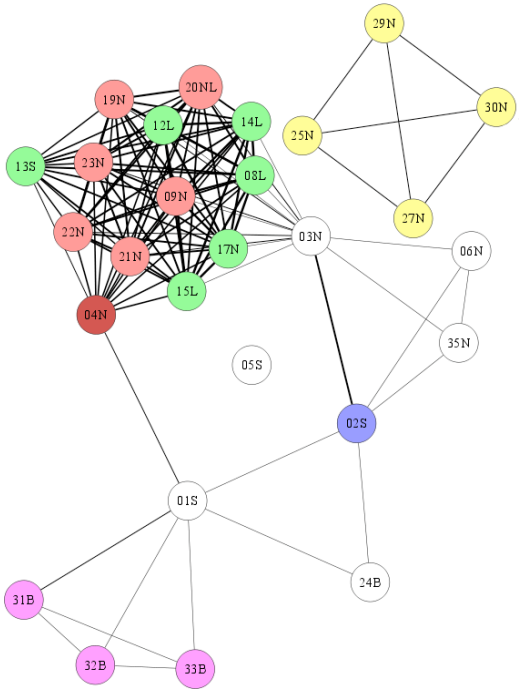







cost (1,1,1)*(27,0,17)=44 8 i-colors 10 g-colors

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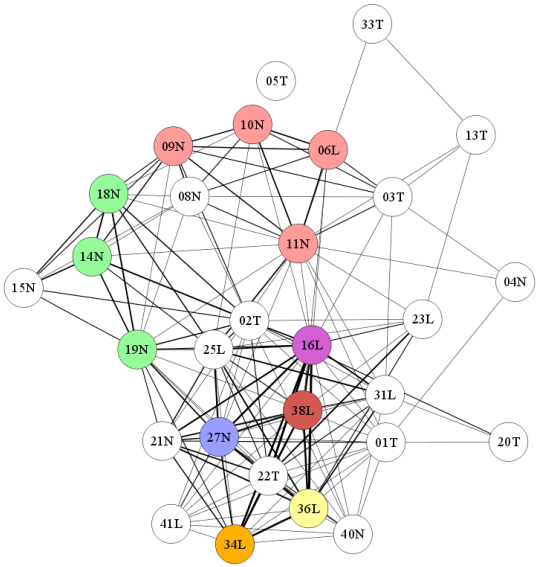
33B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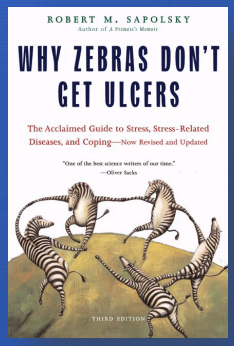
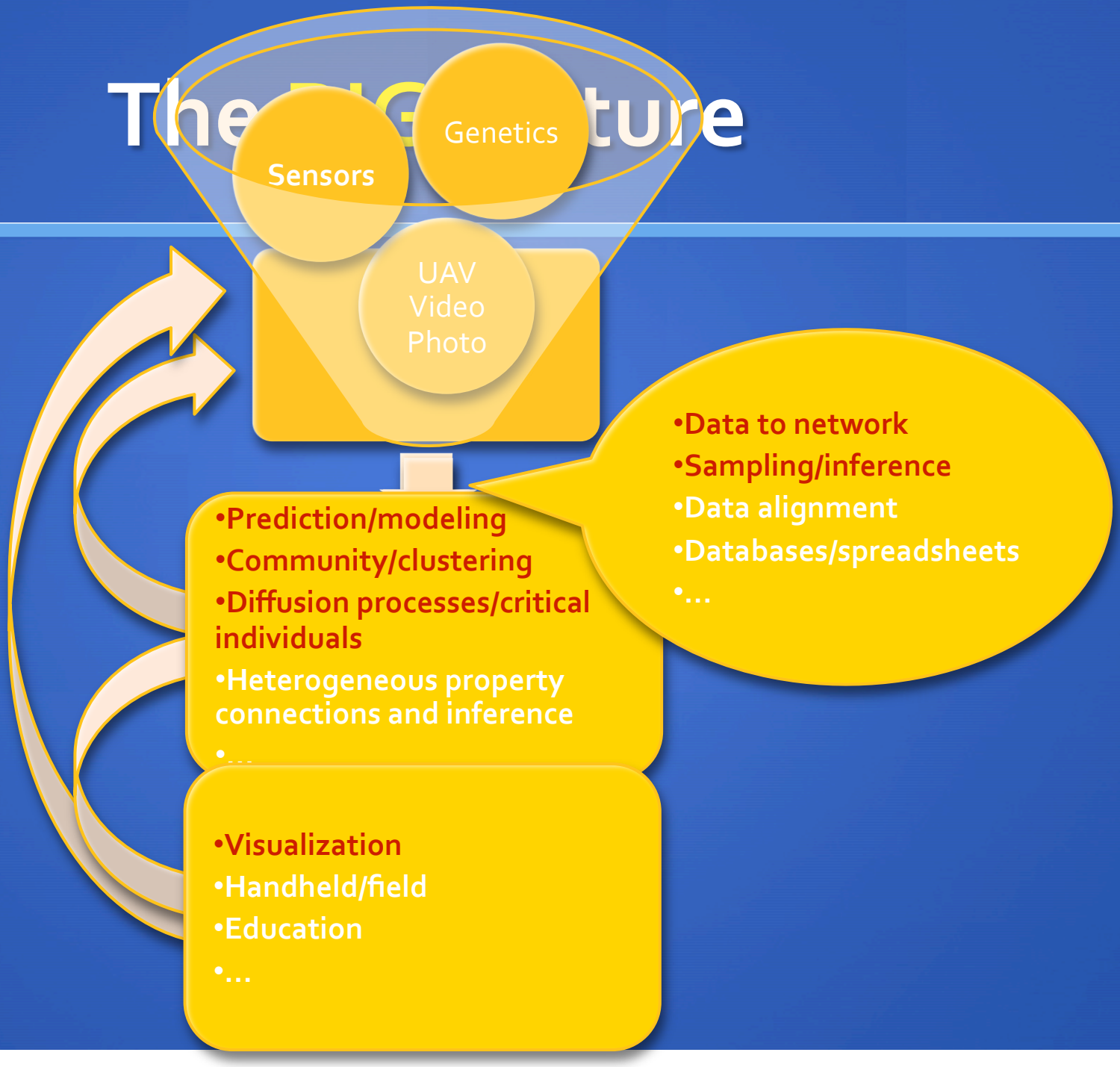
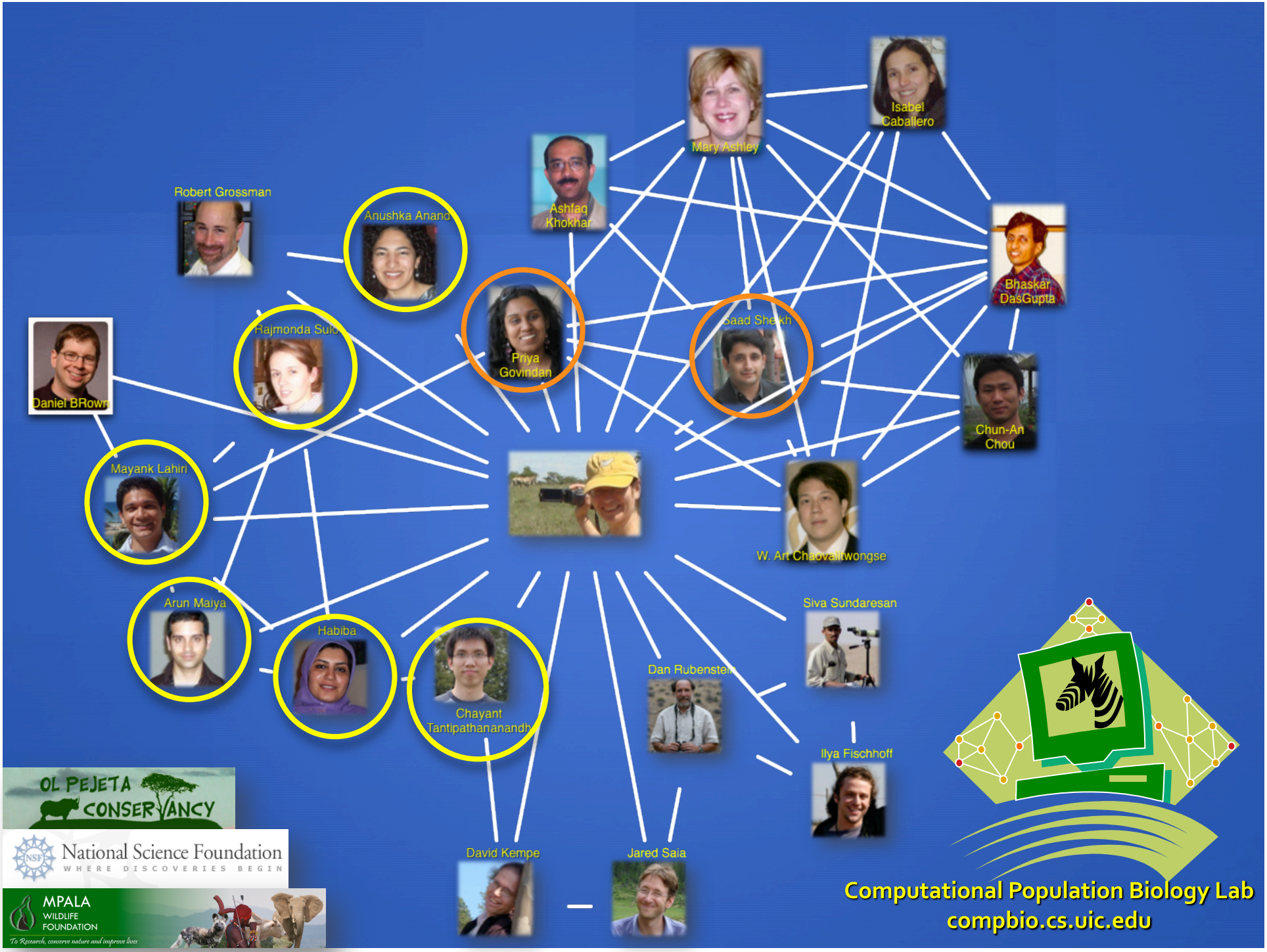
So

- Dynamic is really different from static
- Must develop computational methods that address the order, concurrency, and delay of interactions
- We have a few things but this is just starting – lots more work to do!
  (prediction, communities and other structures, hierarchies, spread, sampling, ….)
- Zebras are better than humans
  (they don't have ulcers—apologies to R. Sapolski)
  - No cellphones or emails: proximity ≈ interaction
  - No privacy issues
  - Can conduct experiments to validate and test
- But everything we do applies to humans



The BIG Picture

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